GEWEX Cloud System Study
Working Group II - Cirrus Cloud Systems
1998 Report

1. Ongoing Activities

The GCSS Working Group on Cirrus Cloud Systems (WG2) initiated two model comparison projects in 1998. The first project, initiated in September and led by David Starr, is the Idealized Cirrus Model Comparison (ICMC) Project involving a variety of cirrus models including high-resolution 2- and 3-dimensional cloud-resolving models (CRMs) with bin-resolved or bulk microphysical treatments, and single column model (SCM) versions of global climate models (GCMs). The second project, initiated in December and led by Ruei-Fong Lin, is the Cirrus Parcel Model Comparison (CPMC) Project involving a comparison of nucleation and ice particle growth processes in a closed Lagrangian parcel model framework for conditions similar to those considered in the ICMC Project. Phase I results are due on January 1, 1999, and March 1, 1999, respectively. A reasonably good level of participation is anticipated (~10 models each).

A survey comparison of ice water fall speed treatments in CRMs was also undertaken. Results of the preliminary survey served to call attention to the significant disparity in the treatment of this very important process although many modelers found it very difficult to characterize this aspect of their models in a way amenable to direct comparison with other models. The difficulty arises from the complex treatments now being used. For example, multiple dependencies of the ice water fall speed diagnosis occur when particle size spectra vary from grid element to grid element even for equivalent ice water content values. Thus, the response was less than desired. The ICMC Project will add substantially to the present results by addressing these difficulties through a protocol that can be implemented in even the most microphysically complex models.

Other notable activities included a keynote GCSS presentation to the American Meteorological Society Cloud Physics Conference in August, strong WG2 participation in the Optical Society of America Topical Conference on Cirrus Clouds (Cirrus-98) in October, and a presentation on WG2 activities and issues to the WGNE-GCSS Workshop at the European Centre for Medium Range Weather Forecasting (ECMWF) in November. WG2 meetings were held during the Cirrus-98 Conference and the ECMWF Workshop.

The WG2 homepage (http://eos913c.gsfc.nasa.gov/gcss_wg2/) continues to serve as an important mechanism for exchange of information and conduct of the group activities. It has been redesigned and now includes a new cirrus literature database (WG2 members), a link to a millimeter cloud radar literature database (GKSS), as well as full documentation of the WG2 projects and surveys such as the ice water fall speed survey.

Funding difficulties in both Europe and the United States for cirrus-related research, especially modeling, and the smallness of the senior-level cirrus modeling community (many WG2 modelers are still in graduate school or recent graduates), remain significant challenges to the success of WG2.

A second WG2 workshop is planned for May 1999. The workshop will be hosted by the GKSS Research Center in Geesthacht, Germany.

Background

WG2 is working toward the GCSS central goal of developing better parameterizations of cloud systems within global climate and weather prediction models, specifically by achieving improved understanding of the coupled physical processes acting to determine the occurrence, properties and effects of cloud systems. WG2 is making a concerted effort at comparison and evaluation of cloud resolving models (CRMs) of cirrus cloud systems in conjunction with corresponding analyses of appropriate observations following the general approach adopted by GCSS. While WG2 members make strong use of observations, the present group activities are focused on idealized situations (ICMC Project) in order to establish fundamental model sensitivities and model differences in this respect. Regional mesoscale models including rather sophisticated treatment of cirrus cloud physics are now available as are a number of 3-dimensional large-eddy simulation (LES) models capable of simulating cirrus cloud systems at high spatial resolution. In the case of cirrus clouds, however, the significant uncertainties in the role of various cloud physical processes dictates a broad approach. Microphysical development is a key issue. Thus, detailed 1-dimensional and parcel models of cloud microphysical development are included in WG2 (CPMC Project). Given the wide range of environmental conditions associated with cirrus cloud systems and the limited resources to cover this range using computationally intensive CRMs, significant utility remains in the 2-dimensional modeling approach. These will play a key role in WG2 model comparison activities. WG2 has achieved significant participation of GCM and NWP researchers with single column modeling (SCM) capability but looks to further expand the participation in this area, especially the NWP community. It is essential that the model comparison and evaluation activities fully engage this community to maximize progress toward the objectives and goals of GCSS.

Observations are a key ingredient of GCSS. Observations guide model development and provide the best measure of the realism and utility of model results. WG2 includes a strong contingent of scientists who bring significant resources in terms of data, analysis capabilities, and understanding. WG2 plans to take strong advantage of the available expertise, data and analyses in its endeavors, including specifically the FIRE Cirrus observational program in the United States, the EUCREX program in Europe and the on-going U.S. DoE Atmospheric Radiation Measurement (ARM) Program. The data sets that have been obtained and the analysis that has been (and can be) done represent an invaluable resource. In particular, data sets suitable for comparative CRM simulations have been obtained, though not without some notable deficiencies. In additional, data obtained during the recent SUCCESS (Subsonic Aircraft: Contrail and Cirrus Effects Special Study) experiment and similar European missions focused on contrails provide essential information on the role of aerosols in determining cirrus microphysical development.

The Atmospheric Radiation Measurement (ARM) program of the U.S. Department of Energy is accumulating a significant volume of high quality cirrus measurements that will be of great utility, including episodic intensive observing periods (IOPs) designed to support SCM comparisons and cloud remote sensing (RCS) objectives. These data sets, that include extensive surface-based active (lidar and radar) and passive remote sensing observations as well as *in-situ* observations during IOPs, will be very important for achieving the objectives of GCSS and WG2 in particular.

Future field experiments that are presently being considered are a tropical cirrus mission (CRYSTAL) in 2001 or 2002 as a follow-on to FIRE. The outlook for future EUCREX activities is unknown. Other missions that may provide useful observations include the NASA TRMM validation experiment near Kwajalein in 1999, missions on stratosphere-troposphere exchange in the tropics in 1998 and again in 2000-2001, and a follow-on to the SUCCESS mission in fall of 2000. There will likely be continuing European contrail missions in the near term. A significant factor of uncertainty in the plans for tropical cirrus missions is the availability/suitability of the NASA WB-57, or comparable, high-altitude aircraft for *in-situ* sampling. Other opportunities to collect suitable cirrus data sets should be exploited to the extent possible.

Key Scientific Issues

Cloud Ice Water Content

Knowledge of the distribution of cloud ice water content (IWC) is the key requirement for characterizing cirrus cloud systems and their role in the climate system. The distribution of IWC is the primary descriptor of cirrus cloud systems, strongly regulates the cloud system radiative effects, and is inherently tied to the upper tropospheric water budget. At present, adequate means to accurately determine such distributions from space do not exist, even in gross terms of vertically integrated ice water path (IWP), though attempts have recently been made to develop such a climatology (Rossow et al or Minnis et al). Development of such a capability is a key observational requirement for the advancement and validation of cirrus cloud system models (CRMs) and climate models (GCMs). *New methods involving active millimeter radar and passive sensing in the far infrared show much promise. It is likely that such measurements will be obtained by the next generation of satellite missions.*

Techniques for determining IWC from surface-based observation (millimeter radar) have been developed but are still being evaluated and refined. The issue here is the sensitivity of the retrieved ice water content to the assumed or estimated particle habit distribution and the lack of sensitivity in the case of cirrus containing appreciable amounts of small ice crystals. Sensor attenuation is another difficulty. There have been significant advances in airborne *in-situ* instrumentation including particle impactors/replicators (and the data processing thereof), holographic particle imaging, and counter-flow virtual impactors (CVI). The latter are capable of determining cloud ice water content contained in particles larger than some selected threshold size. These advancements in *in-situ* instrumentation are essential for the development of radar-based methods. In turn, the radar-based methods provide a highly suitable means to obtain the data sets required for development and validation of space-based techniques. Results of comparisons between the *in-situ* instruments deployed during SUCCESS have been very encouraging and indicates the utility of using *in-situ* measurements for model validation and remote sensing developments.

Role of Atmospheric Aerosols

Ambient aerosol populations may play an important role in determining cirrus cloud properties, especially for the extensive, weakly-forced, optically-thin, cirrus clouds that are ubiquitous in the tropics and common in middle latitudes. Assessment of the importance of these processes requires adequate characterizations of the ambient aerosol and ice crystal populations. Recent advances in instrumentation have enabled collection of relevant data sets that allow for the first time a useful, if still incomplete, characterization. In particular, improved characterization of the population of small ice crystals and significant sampling of the aerosol populations has been achieved. Such data are available from the recent European missions focused on contrails as well as the SUCCESS mission in 1996 and WAM in 1998. Analysis of these data is progressing well and the results will be quite timely for WG2.

A key issue here is determining the activity spectrum of the aerosol population. Results from SUCCESS indicates some progress in using *in-situ* observations toward this end. Laboratory results have also provided very useful information and should be continued. *Recent field measurements (WAM) indicate that aerosol composition in the upper troposphere may be much more complex than previously believed, i.e., individual aerosol particles may contain numerous elements. This indicates that heterogeneous nucleation may be more significant than recent studies might indicate.* It is also noteworthy that there have been recent theoretical advances in explaining the nature of crystal habit development in cirrus. These results await further exploitation.

Determination of the effects of ambient aerosol population on cirrus clouds requires observations and models capable of resolving the local motions that actually govern the operating nucleation and growth scenarios. Such motions include gravity waves, small-scale convection, 2-dimensional turbulence and other mesoscale circulations. As such, adequate characterization of the motion and turbulence fields in cirrus and comparison to model simulations must be a key aspect of WG2 activities. Suitable observation were obtained by EUCREX and during FIRE Cirrus-II. Analysis of these data is on-going. *Recent studies indicate that mesoscale circulations may play a more significant role than previously believed in initiating cirrus events. Such circulations are not generally resolved in CRMs simulations. Reconciliation of this aspect is an area of on-going research.*

Role of Radiative Process

Much progress has been made as a result of EUCREX and FIRE in defining relationships between cirrus cloud microphysical properties and cloud radiative properties. Knowledge of particle habit and size distribution and their effects on the radiative fields has advanced markedly. This has led to substantial improvements in surface-based, airborne, satellite-based remote sensing of cirrus clouds. Significant issues remain, however, such as the possibility of enhanced cloud absorption of solar radiation. Studies to-date indicate a very significant role of radiative process in affecting dynamical and thus microphysical development in cirrus. Thus, another key aspect of cirrus model comparisons within WG2 will be to examine the impact of different treatments of cloud radiative processes on cirrus cloud simulations. Solar absorption is an area of particular concern.

GCM Simulations of Cirrus Cloud Systems

In addition to the above foci on fundamental cloud physical processes, the question of how adequate are GCM simulations of cirrus cloud systems must be addressed. In the context of these large-scale models, issues involving the upper tropospheric water budget and dynamical processes are crucial. Transports of water vapor to the upper troposphere largely determine the subsequent formation of cirrus clouds. It is unknown whether such transports are realistically simulated in GCMs or even if mesoscale processes are highly involved in such processes. *Participation of NWP models in such studies would be highly beneficial.* Detailed case study comparisons of mesoscale CRM simulations and GCM and NWP simulations in conjunction with appropriate analyses may help resolve this issue. Also of central importance is the role of unresolved small vertical motions in determining properties of cirrus cloud systems. By affecting the actual microphysical composition and, maybe more importantly, the spatial distribution of cloud properties, such motions play a significant role in determining the dehydration of the upper troposphere through the ice particle fallout process that is so prevalent in cirrus clouds. Quantification of these effects can be accomplished through CRM simulations in comparison to GCM simulations, possibly suggesting approaches for adequate parameterization of these effects in GCMs. Statistical analysis of in-situ observations are also quite useful and have been recently used to quantify the bulk variability found in cirrus.

Climatological data sets derived from remote sensing observations from satellites, such as cloudiness from ISCCP and upper tropospheric humidity from TOVS, and more recently from ground-based active sensors, such as lidar and millimeter wavelength radar, provide an extremely important quantitative basis for evaluating GCM performance in terms of cloud cover, frequency of occurrence, vertical location and depth, and cloud vertical structure, as well as upper tropospheric humidity (UTH). Preliminary comparisons indicate significant deficiencies in GCM simulations as regards cirrus cloudiness and UTH. It is likely that these factors are highly related and provide a strong motivation for the WG2 activities described here. The cause of these deficiencies may reside in the treatment of cloud physical processes, the account of dynamical processes on unresolved scales from individual cloud elements to mesoscale circulations, and/or the treatment of transports by the resolved flow. Separation of such processes can be achieved in the analysis of model simulations while it is quite difficult from an observational perspective. This is an area where WG2 can make an important contribution.

In summary:

• Observations of cloud ice water distributions on the scale of cirrus cloud systems are a key requirement for system-scale model validation. New satellite missions offer the possibility that adequate characterizations may be possible in the not too distant future. Ground-based remote sensing now offers highly useful data.

• Aerosols and their potentially important role in determining cirrus microphysical composition remain an open issue. Recent advances have significantly increased our knowledge of the ambient aerosol population and the dynamical factors involved in the realization of their possible effect. However, given the complexity of the natural environment, it is likely that definitive answers depend on the success of on-going fundamental laboratory studies.

• Radiative processes are an important component of the physical processes involved in determining cirrus cloud properties, in addition to being a primary mechanism for cirrus clouds to affect other components of the climate system. Much progress has been achieved, especially in remote sensing applications, but the model implementations have not yet taken full advantage and remain subject to significant uncertainties.

• Dynamical processes represent a key connection between other physical cloud processes and are intimately involved in scaling issues that are maybe the most fundamental and intractable difficulty in adequately representing cloud systems in large-scale models.

• Observations are absolutely crucial in supporting efforts to improve present capabilities to simulate cloud systems and more generally, weather and global climate. Much can be learned from increased comparison of large-scale models and observations.

Report on Cirrus-98 Conference

A first-ever conference devoted entirely to cirrus cloud research was held in October 1998 under the sponsorship of the Optical Society of America. The conference was organized as a series of review papers covering all aspects of cirrus cloud research. Numerous excellent posters were also given. A review book (Oxford University Press) is planned. About 100 research scientists, including many graduate students and recent graduates, participated. Limited travel support was provided by NASA's Radiation Sciences Program headed by Dr. Robert Curran. The agenda may be obtained from the GCSS WG2 homepage.

Three papers reported CRM results from WG2 ICMC Project simulations and results of CRM simulations of cirrus were reported in 2 other papers. Recent progress in laboratory studies characterizing cirrus crystal habit development and the role of aerosols in cirrus microphysical development were also reported. Significant impressions/conclusions of the conference, of most relevant to GCSS WG2, were:

- There has been much progress over the last 25 years in instrumentation, data collection, analysis methods and observing strategies that have led to substantial progress in knowledge of the basic properties and characteristics of cirrus cloud systems.

- Accurate measurements of cloud ice water content and cloud ice water path are essential for further progress, especially global satellite-based observations. The future holds much promise in this area both near-term and longer-term.

- Cloud-resolving models represent a key link between field observations and global models that must be further exploited. Areas where additional understanding and/or measurements are needed include:
    - ice water fall speed
    - characterization of entrainment and detrainment processes in cirrus, in stable and convective environments and especially in sheared environments
    - characterization of solar absorption in cirrus and its effects
    - characterization of the role of mesoscale dynamical processes
    - determining the role of ambient aerosol population, including composition, on subsequent cirrus microphysical development

- Observations of tropical cirrus cloud systems, suitable for CRM studies, are critically needed.

GCSS WG2 Projects

Idealized Cirrus Model Comparison Project - Background

There is a wide range of possible environmental parameters, and combinations thereof, that may be associated with cirrus cloud occurrence, e.g.,

- relatively warm versus cold (high) cirrus,
- weak to strong forcing (generation via large scale uplift) versus dissipation,
- nighttime (infrared only) versus daytime (infrared and solar) radiative environments and the seasonal and latitudinal variations thereof,
- very stable to conditionally unstable thermal stratification,
- strongly sheared to weakly sheared versus no vertical shear of horizontal wind,
- variations of composition and concentration of the ambient aerosol population.

Discussions at the GCSS WG2 Williamsburg Workshop resulted in the following conclusions as to a highest priority set of idealized test cases for model comparison:

- A night (infrared only) simulation of an horizontally uniform, initially supersaturated and conditionally unstable (convective) layer of a representative thickness in an unsheared (no mean horizontal flow) environment subject to constant and relatively weak vertical forcing (3 cm s^{-1}) would serve as the optimal baseline idealized test case for the WG2 comparison of cirrus cloud models.
- The baseline case should have 2 variants: a warm cirrus case and a cold cirrus case. The warm case may be regarded as corresponding to an extratropical "synoptic" cirrus situation while the cold cirrus may be interpreted as high cloud associated with the subtropical jet stream in mid-latitudes.
- Further variants of the baseline warm and cold cirrus cases should be constructed to test model sensitivity to infrared radiative processes (baseline versus a no-radiation case).
- A highly useful variant of the baseline warm and cold cirrus cases would be to consider the dissipation of the cloud subsequent to elimination of the vertical forcing at some point in the simulations.

While these test case simulations already represent a very significant amount of computations, especially for multi-dimensional models, and form the core of the idealized test case model comparison project, additional tests were strongly encouraged, specifically:

- cases with a somewhat stable thermal stratification would enable assessment of relative sensitivity to environmental static stability.

- cases with weak-to-moderate vertical wind shear should be compared to explore potential divergence in model response to this environmental factor.

The Workshop concluded that the degree of uncertainty about the treatment of solar radiation in cirrus clouds was such that comparisons of an idealized daytime case should be deferred. Consideration of model sensitivity to ambient aerosol population was similarly deferred. Model comparisons for cirrus generation via outflow from deep convective systems, orographic lifting (lenticular) or aircraft (contrails) were also deferred in the interests of improved initial focus, i.e., first steps first. Each of these situations is of very high interest to WG2, especially the anvil comparison, and will be considered at some time in the near future, possibly in conjunction with other GCSS working groups.

Idealized Cirrus Model Comparison Project - Definition

There are two required BASELINE simulations for the Idealized Cirrus Model Comparison Project – a warm cirrus case (-40°C) and a cold cirrus case (-60°). There are four additional simulations that are "highly desired" and are simple variants of these two cases (no-radiation and cloud dissipation cases). Four "desired" cases and four "optional" cases are also defined. These are designed to reveal differences in model sensitivity to static stability and vertical wind shear. Again, they are variants of the two Baseline cases. All participating modelers are to perform both required simulations. If at all practical, the "highly desired" simulations should also be done with the remainder depending on the resources available.

Specific recommendations are made as to spatial domain and model resolution. While not feasible for all models, a horizontal resolution of 50 meters and a horizontal domain of 10 km is recommended as optimal. The models are to be run for 3 hours of simulated time beginning with an initial supersaturated (120% with respect to ice) layer of 1 km thickness with unstable thermal stratification over its upper half to ensure cloud formation in all models. To facilitate participation of the SCM community, the cloud environment is resolvable at a vertical resolution of 500 meters. Vertical motion forcing (large-scale ascent) is specified via an imposed corresponding large-scale cooling rate. This also simplifies the problem and facilitates participation by a wide range of models. Required model output includes profiles at 10 minute intervals of horizontally averaged ice water content, ice particle number density and similar parameters for liquid particles if present, profiles of cloud optical depth and broadband radiative fluxes, profiles of potential temperature and turbulence parameters enabling the evaluation of buoyancy flux profiles.

Selected fields are also requested, specifically the vertically integrated ice water path, to enable a common characterization of the frequency distributions within the model domains. Experimenters were also requested to archive as much of their model fields as possible at standard 10 minute intervals to facilitate subsequent analysis.

Idealized Cirrus Model Comparison Project - Ice water Fall Speed Comparison

As part of the ICMC Project, experimenters were also requested to calculate an effective ice water fall speed, essentially the vertical ice mass flux divided by the ice water content, for each grid volume at selected time steps and to form statistical summaries for a standard set of 51 bins on a logarithmic ice water content scale. This provides a common basis for comparison of the model realizations of ice water fall speed no matter what the internal model design.

Cirrus Parcel Model Comparison Project

The purpose of this project is to compare various detailed models of cirrus particle nucleation and subsequent growth. Such models are presently used to develop the treatments used in the most sophisticated multidimensional CRMs. These include Lagrangian parcel models as well as by parcel or one-dimensional versions of multi-dimensional models. A relative simple series of initial calculations is requested. Two series of calculations are made to consider warm and cold cirrus situations very comparable to the environments considered in the ICMC Project. An initial aerosol population is given, and calculations are then made for 3 different assumed updraft speeds: 4 cm s^{-1}, 20 cm s^{-1} and 1 m s^{-1}. The parcels are assumed thermodynamically and dynamically closed and the calculation is made until the parcel has lifted to 800 meters above its initial location at heights of 8.3 and 13.4 km. Output parameters are ice relative humidity with respect to ice (RHI), temperature, ice number concentration, and ice water content at 5 meter height intervals starting from the initial state. Detailed information is also requested at the moment when maximum RHI is achieved. The calculations are made using whatever ice nucleation mechanisms/schemes are implemented in the models. For those that have a separate explicit treatment for homogeneous nucleation, a second set of calculations are requested where only that mechanism is permitted,

As in the ICMC Project, other factors may also be investigated after the initial phase of this project, including effects of gross changes in the aerosol particle size distribution, effects of aerosol particle composition, and direct radiation effect on growth rate.

2. New Results

Models

There has been significant recent progress in modeling cirrus clouds. A number of 3-D models (LES and CRM) now incorporate rather sophisticated microphysical and radiative treatments of cirrus. Some models include explicit treatment of particle size distribution as well as ice initiation processes (aerosols). There also continues to be strong 2-dimensional cirrus modeling efforts. Recent work shows a strong concern with ice initiation processes and their effects on cirrus. Comparison to observations is a strong element of recently published modeling studies, though deficiencies in the available observations continues to be a significant problem. Simulations have compared very favorably with observations of orographic lenticular cirrus clouds.

Recent new modeling results of some importance include:

1) A recently published study (Khvorstanyov and Sassen) found that ice-saturated "equilibrium" conditions are not achieved in many cirrus clouds, especially at cold temperatures where supersaturations of 10% may be maintained within the cloud due to the slowness of the diffusional growth mechanism at these low vapor pressures. This has very significant implications for the bulk treatment of cirrus cloud formation in GCMs as well as for the role of aerosols in cirrus cloud processes.

2) A new theory has been published that details the diffusional growth mechanism of individual cirrus ice crystals as regards habit.

3) A number of highly detailed modeling studies have been published on contrails.

Observations

Lidar and millimeter-radar observations of cirrus clouds are providing an invaluable resource. Besides supporting CRM studies focused on individual observed cases, analysis of extensive long-term data sets are beginning to provide climatological information that is directly applicable for validation of GCMs.

Analyses of the extensive microphysical, aerosol and humidity observations obtained during the 1996 SUCCESS mission provide the best picture yet of the relationship between aerosol population and cirrus cloud composition. The lack of correspondence found between the numbers of ice crystals and the numbers of contained nuclei is of note. Also of particular importance are the results of detailed comparisons between the various microphysical sensors where good agreement was generally found in terms of IWC. This was not expected. The complexity of aerosol composition in the upper troposphere, found during WAM, was also unexpected and may have significant bearing on how nucleation processes actually operate in cirrus and on the approaches used to simulate these processes.

Analysis of fine-scale observations of dynamical processes in cirrus is yielding significant insights as new analysis techniques are applied, especially wavelet analysis, to high resolution measurements. The results show much promise for validation of CRMs in these regards, something that has not been satisfactorily done to this point. A significant finding is that mesoscale circulations, not generally present in CRM simulations, may play a much more significant role than previously believed in cirrus cloud systems.

3. Observational Requirements for Future Field Experiments

The priorities for future field experiments are fairly well-defined. The highest priority is for an experiment on tropical cirrus generated by deep convective systems. While CPEX produced some very useful data sets on tropical cirrus anvil properties and TOGA-COARE produced useful characterizations of tropical deep convective systems, there is a strong need to have a data set that enables the relationship between the generating deep convection and the evolving cirrus system to be quantified. To be of most utility, measurements of convective mass and moisture flux must be acquired in conjunction with extensive measurements of anvil evolution. This is the connection where GCM modelers have almost no observational guidance and yet controls the upper tropospheric water budget in their models to a strong degree. Planning for such an experiment are underway. A key requirement is that the data sets be adequate to support CRM studies using both deep convective models as well as cirrus system models. Knowledge of the large-scale environment is essential for this application.

It should also be noted that the ice water fall speed is another model parameter with a great influence on the simulations, not only in CRMs but also in GCMs. Increased efforts to validate present treatments of this process using field data are needed. Doppler cloud radar (mm-wavelength) offers very real possibilities to directly address this need.

There is also a continuing need for better measurements related to aerosol influence on cloud microphysical properties. There is continuing instrument development and the results of present comparative analyses will likely suggest important new measurement to test the developing theories and capabilities. However, laboratory investigations will likely be key. Similarly, remote sensing concerns will continue to drive focused experiments on retrieval of cirrus cloud properties.

4. Action Plan for 1999

A second GCSS WG2 Workshop will be held in 1999. The focus of this workshop will as follows:

a) results from the ICMC Project
b) results from ice water fall speed comparison
c) results from the CPMC Project
d) definition of possible second stage for both ICMC and CPMC Projects
d) design of a Cirrus Anvil Project, in conjunction with WG4
e) consideration of observed warm and cold cirrus cases for adoption as possible WG2 model comparison/evaluation cases

The Idealized Cirrus Model Comparison (ICMC) Project involves a set of permutations of two simple cases -- a warm cirrus case (-40°C) and a cold cirrus case (-60°). The Cirrus Parcel Model Comparison (CPMC) Project is considering similar situations.

Observational test cases that will be considered include a case observed during EUCREX to the east of northern Scotland (24 September 1993 "warm" cirrus case) and a case observed at the ARM CART site in Oklahoma (19 April 1994 "cold" cirrus case). These single cirrus cloud layer cases are reasonably similar observational counterparts to the idealized (ICMC) test cases. Papers focused on each of these cases will soon be available from the WG2 homepage, including results of a 3-dimensional CRM simulation of the EUCREX case as well as extensive analyses of the observations. Alternative cases from ARM, or elsewhere, will be considered as appropriate.

A more complex and challenging case that may considered is the 26 November 1991 case observed during FIRE Cirrus-II where definition of the regional environment benefits markedly from the enhanced observations at that scale. This proposed observational test case will promote and benefit from the participation of the broadest community, both in terms of models (scales) and observational guidance.

WG2 will work with WG4 to design of a cirrus anvil test case. The activity is regarded as high priority by many of the WG2 and WG4 participants. The outlook is for development of a joint project in 1999 with a workshop in the late-1999. Joint activities with GCSS WG3 concerning cirrus clouds associated with well-developed precipitating extratropical cyclones are also envisioned. The WG3 BASE case may be of sufficient interest to WG2 to merit consideration as a joint case. Participation of members of WG3 and WG4 in the WG2 ice water fall speed comparison is strongly encouraged.